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Description

METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM

Cross Reference To Related Applications

[0001] This is a co-pending Application No. XX/XXXXXX, filed on the same day with the present patent application, entitled "METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM" and assigned to the same assignee, the contents of which are incorporated herein by reference.

Background of Invention

[0002] 1. Field of the Invention

[0003] The invention relates to an apparatus for use in an OFDM system and a method thereof , and more particularly, to an apparatus for detecting ISI/ICSI in an OFDM system and a method thereof.

[0004] 2. Description of the Prior Art

[0005] Most OFDM transceivers suffer from well-known problems of inter-symbol interference (ISI) and inter-carrier inter-

ference (ICI). An additional guard interval (GI) is added between two symbols to recover the ISI and the ICI. When receiving a packet including a plurality of symbols, a conventional OFDM receiver detects the boundary of each symbol, removes GI of each symbol according to the detected boundary of the symbol, and then demodulated the symbol through Fast Fourier Transform (FFT) operation. However the detected boundary may not be reliable owing to the influence of multi-path and other factors.

[0006] One conventional art applied to improve the precision of boundary detection is to estimate the time shift of the detected boundary according to the frequency domain linear phase shift of the demodulated data. Another conventional art disclosed is to estimate the time shift of the detected boundary according to the channel impulse response of the symbol. However, when the delay spread phenomenon is too severe, the ISI and ICI problem cannot be recovered by both of the two conventional techniques and the boundary detection may be imprecise which may cause divergence or even failure in receiving when receiving symbols.

SUMMARY OF INVENTION

[0007] It is therefore one of the objects of the claimed invention

to provide a method and an apparatus of detecting ISI/ICSI in an OFDM system for use in boundary tracking to solve the above-mentioned problem.

[0008] According to an embodiment of the claimed invention, a method of detecting inter-symbol interference (ISI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system is disclosed. Each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers. The disclosed method comprises the steps of computing a first correlation value representing the correlation between a plurality of first signals of a first symbol and a plurality of second signals of a second symbol previous to the first symbol, wherein the first and the second signals are both transmitted via the same sub-carriers; computing a second correlation value representing the correlation between the first signals and a plurality of third signals of a third symbol next to the first symbol, wherein the first and the third signals are both transmitted via the same sub-carriers; comparing the first correlation value with the second correlation value; and adjusting the timing of the boundary according to the comparison result.

[0009] According to an embodiment of the claimed invention, an

apparatus of detecting inter-symbol interference (ISI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system is disclosed. Each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers. The disclosed apparatus comprises a first correlator for computing a first correlation value representing the correlation between a plurality of first signals of a first symbol and a plurality of second signals of a second symbol previous to the first symbol, wherein the first and the second signals are both transmitted via the same sub-carriers; a second correlator for computing a second correlation value representing the correlation between the first signals and a plurality of third symbols of a third symbol next to the first symbol, wherein the first and the third signals are both transmitted via the same sub-carriers; a comparator for comparing the first correlation value with the second correlation value; and a timing controller for adjusting the timing of the boundary according to the comparison result.

BRIEF DESCRIPTION OF DRAWINGS

[0010] Fig.1 is a schematic diagram of an ISI detector according to one embodiment of the present invention.

[0011] Fig.2 is a schematic diagram of an ISI detector according

to another embodiment of the present invention.

[0012] Fig.3 is a schematic diagram of an ICSI detector according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0013] Please refer to Fig.1, which is a schematic diagram of an ISI detector 20 according to one embodiment of the present invention. As shown in Fig.1, the ISI detector 20 is coupled to a timing controller 62, and the ISI detector 20 comprises two correlators 21, 41 for respectively generating a correlation value R_{pre} and a correlation value R_{nxt} and a comparator 60 to compare both correlation values. The correlation value R_{pre} represents the magnitude of the ISI caused by the previous symbol, and the correlation value R_{nxt} represents the magnitude of the ISI caused by the next symbol. The comparator 60 is used to compare the correlation value R_{pre} with the correlation value R_{nxt} and generate a control signal Sc according to the comparison result. The timing controller 62 is used to control the timing of a boundary of an OFDM system according to the control signal Sc.

[0014] As shown in Fig.1, the correlator 21 of this embodiment comprises conjugating units 22,......, 32, multipliers 24,......, 34, low-pass filters 25,......, 35, absolute value

calculating units 26,......, 36, and a summation unit 28. The conjugating units 22,......, 32 are used for respectively generating conjugated pilot data $P_1(n)^*$,......, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$,......, $P_k(n)$ that was transmitted using the current symbol. The multipliers 24,......, 34 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$, $P_k(n)^*$ with a corresponding comparison data

$$\hat{P}_1(n-1)$$

,......,

$$\hat{P}_k(n-1)$$

that was transmitted using the previous symbol. The low-pass filters 25,....., 35 are used for averaging the product values outputted from these multipliers 24, 34, respectively. The absolute value calculating units 26,......, 36 are used for generating absolute values of the average values corresponding to the product values. The summation unit 28 is used for generating a correlation value R_{pre} by summing these absolute values.

[0015] Similarly, the correlator 41 comprises conjugating units

42,......, 52, multipliers 44,......, 54, low-pass filters 45,......, 55, absolute value calculating units 46,......, 56, and a summation unit 48. The conjugating units 42,......, 52 are used for respectively generating conjugated pilot data $P_1(n)^*$,......, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$, ..., $P_k(n)$ that was transmitted using a current symbol. The multipliers 44,......, 54 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$,......, $P_k(n)^*$ with a corresponding comparison data

$$\hat{P}_1(n+1)$$

,......,

$$\hat{P}_k(n+1)$$

that was transmitted using the next symbol. The low-pass filters 45,......, 55 are used for averaging the product values outputted from these multipliers 44, ...,54, respectively. The absolute value calculating units 46,......, 56 are used for generating absolute values of the average values corresponding to the product values outputted from these multipliers 44, ..., 54. The summation unit 48 is used

for generating a correlation value R_{nxt} by summing these absolute values.

[0016] According to the well-known theorem of correlation, the following Equations (1) and (2) are used to better explain operations of the correlators 21, 41.

[0017]

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n-1) \cdot P_k(n)^*])$$

Equation (1)

[0018]

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n+1) \cdot P_k(n)^*])$$

Equation (2)

[0019] $P_k(n)^*$ denotes the conjugated pilot data transmitted using an n^{th} symbol via the a k^{th} sub-carrier,

$$\hat{P}_k(n-1)$$

denotes the comparison data transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and

$$\hat{P}_k(n+1)$$

denotes another comparison data transmitted using an $(n+1)^{th}$ symbol via a k^{th} sub-carrier. Please note that the more sub-carriers that are considered, the more reliable result will be generated.

[0020] This embodiment of ISI detector is for use in the OFDM system that the pilot of different symbols transmitted via the same sub-carrier have known but different predetermined values. As the result,

$$\hat{P}_k(n-1)$$

and

$$\hat{P}_k(n+1)$$

denote those known predetermined values of pilot in this embodiment. Since the pilots of two different symbols are different, the correlation between pilots of different symbols is due to the interference between these two symbols. Therefore, if the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly introduced from using the previous symbol, which is due to the timing of the detected boundary is ahead of that of the ideal boundary. In this manner, the timing

controller 62 delays the timing of the boundary according to the control signal Sc outputted from the comparator 60. On the otherhand, if the correlation value R_{pre} is less than the correlation value R_{nxt}, it means that the interference is mainly introduced from the following symbol, which is due to the timing of the detected boundary lags behind that of the ideal boundary. In this manner, the comparator 60 outputs the control signal Sc to the timing controller 62 for advancing the timing of the boundary. As a result, the ISI effect is alleviated.

[0021] Please refer to Fig.2, which is a schematic diagram of an ISI detector 80 according to another embodiment of the present invention. As show in Fig.2, the ISI detector 80 comprises two correlators 90, 110 and a comparator 120. The correlators 90, 110 are used for generating correlation values R_{pre} and R_{nxt}, respectively. The comparator 120 compares the correlation value R_{pre} with the correlation value R_{nxt} for outputting a control signal Sc to control the timing controller 129.

[0022] In this embodiment, the correlator 90 has 1st delay circuits 91a,......, 101a, 2nd delay circuits 91b,......,101b, conjugating units 92,......, 102, multipliers 93,......, 103, equalizers 94a,......, 104a, slicers 94b,......,104b, low-

pass filters 95,......, 105, absolute value calculating units 96,......, 106, and a summation unit 98. Concerning the other correlator 110, it has 1st delay circuits 111, ..., 121, conjugating units 112,......, 122, multipliers 113,......, 123, equalizers 114a,......, 124a, slicers 114b,.......,124b, low-pass filters 115,......, 125, absolute value calculating units 116,......, 126, and a summation unit 128. Please note that the components shown in Figs.1 and 2 that have the same name have substantially the same functionality and operation. The related description, therefore, is not repeated for simplicity.

[0023] For an OFDM system having pilot transmitted via the same pilot sub-carrier using different symbols corresponding to the same value, the ISI detector 80 is preferably utilized. As shown in Fig.2, the comparison data

$$\hat{Q}_1(n-1)$$

,......,

$$\hat{Q}_k(n-1)$$

are the decision results from received data signals $Q_1(n-1)$,......, $Q_k(n-1)$ through the corresponding equalizers 94a,

......,104a, and the slicers 94b,......,104b, wherein the data signals $Q_1(n-1)$,......, $Q_k(n-1)$ are delayed by the corresponding 1st delay circuits 91a,......,101a, 2nd delay circuits 91b,......,101b and then transmitted to the equalizers 94a,......,104a. Regarding the comparison data signals

$$\hat{Q}_1(n+1)$$

,......,

$$\hat{Q}_k(n+1)$$

, they are generated by directly equalizing and slicing the data signals $Q_1(n+1)$,......, $Q_k(n+1)$ with the corresponding equalizers 114a,......, 124a and slicers 94b,......,104b .

[0024] It should be noted that the symbol Q(.) represents the received data signal of the corresponding sub-carrier and the symbol

$$\hat{Q}(.)$$

represents the result of equalizing and slicing of the data signal of Q(.).

[0025] With the circuit configuration shown in Fig.2, the correla-

tion values R_{pre} and R_{nxt} are computed according to the following equations (3) and (4).

[0026]

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n-1) \cdot Q_k(n)^*])$$

Equation (3)

[0027]

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n+1) \cdot Q_k(n)^*])$$

Equation (4)

[0028] $Q_k(n)^*$ denotes the conjugated data signal transmitted using an n^{th} symbol via the a k^{th} sub-carrier ,

$$\hat{Q}_k(n-1)$$

denotes the equalized comparison data signal transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and

$$\hat{Q}_k(n+1)$$

denotes another equalized comparison data signal transmitted using an $(n+1)^{th}$ symbol via a k^{th} sub-carrier.

[0029] Therefore, if the correlation value R_{pre} is greater than the

correlation value R_{nxt}, it means that the interference is mainly caused by the previous symbol, in this manner, the timing of the boundary is delayed by the timing controller 114a. If the correlation value R_{pre} is smaller than the correlation value R_{nxt}, it means that the interference is mainly caused by the next symbol, in this manner, the timing is advanced by the timing controller 129. In the end, the ISI effect is alleviated.

[0030] It is well-known that the ISI might be introduced by adjacent sub-carriers as well. That is, inter-carrier-symbol-interference (ICSI) occurs. Please refer to Fig.3, which is a schematic diagram of an ICSI detector 160 according to the third embodiment of the present invention. In this embodiment, k sub-carriers of the different symbols for transmitting data are chosen through decision directed method for determining ISI. Since the data of two different sub-carriers are different, the correlation between the data of different sub-carriers is due to the interference between these two sub-carriers.

[0031] The ICSI detector 160 has two correlators 130, 150 and a comparator 170. The correlator 130 includes conjugating units 131,......, 141, equalizers 132a, 132b,......, 142a, 142b, slicers 132c,132d......,142c,142d, multipliers 133a,

133b,......, 143a, 143b, low-pass filters 134a, 134b,......, 144a, 144b, absolute value calculating units 136a, 136b,......, 146a, 146b, and a summation unit 138. Similarly, the correlator 150 includes conjugating units 151,......, 161, equalizers 152a, 152b,......, 162a, 162b, slicers 152c,152d,......162c,162d, multipliers 153a, 153b,......, 163a, 163b, low-pass filters 154a, 154b,......, 164a, 164b, absolute value calculating units 156a, 156b,......, 166a, 166b, and a summation unit 158.

[0032] I t is obvious that the correlators 130, 150 have substantially the same circuit architecture. However, the data inputted into the correlators 130, 140 are different. Please note that the components shown in Figs.1, 2, and 3 that have the same name have substantially the same functionality and operation. The related description, therefore, is not repeated for simplicity. The following equations (5) and (6) are used to better explain operations of the correlators 130 and 150.

[0033] $$R_{pre} = \sum_{k=1}^{K}\left(abs(E[\hat{D}_{k-1}(n-1)\cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n-1)\cdot D_k(n)^*])\right)$$

[0034] Equation (5)

[0035] $D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier,

$$\hat{D}_{k-1}(n-1)$$

denotes a decision result of data $D_{k-1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and

$$\hat{D}_{k+1}(n-1)$$

denotes a decision result of data $D_{k+1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. As a result, the correlation value R_{pre} is computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. That is, the$_{\text{ICSI generated from the adjacent (k-1)th}}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a previous symbol is calculated according to the above Equation (5).

[0036] $$R_{nxt} = \sum_{k=1}^{K}\left(abs(E[\hat{D}_{k-1}(n+1)\cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n+1)\cdot D_k(n)^*])\right)$$

[0037] Equation (6)

[0038] $D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier,

$$\hat{D}_{k-1}(n+1)$$

denotes a decision result of data $D_{k-1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and

$$\hat{D}_{k+1}(n+1)$$

denotes a decision result of data $D_{k+1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. It is clear that the correlation value R_{nxt} is also computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. In other words, the ICSI generated from the adjacent (k-1)th sub-carrier and $(k+1)^{th}$ sub-carrier using a following symbol is calculated according to the above Equation (6). Please note that data processed by correlators 130 and 150 are transmitted via data sub-carriers not pilot sub-carriers. Finally, the comparator 170 shown in Fig.3 compares the correlation value R_{pre} with the correlation value R_{nxt} for searching a greater one. If the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly caused by the previous symbol, in

this manner, the timing of the boundary would be delayed by the timing controller 172. If the correlation value R_{pre} is smaller than the correlation value R_{nxt}, it means that the interference is mainly caused by the next symbol, in this manner, the timing of the boundary of the OFDM system would be advanced by the timing controller 172. Therefore, the ICSI effect is alleviated.

[0039] In the above embodiments, please note the absolute values are directly summed to generate the wanted correlation values R_{pre} and R_{nxt}. However, the correlation values R_{pre} and R_{nxt} can be generated by using square values instead of the absolute values. For instance, each of the product values is squared before the summation value is calculated. That is, the above Equations (1)-(6) are replaced with the following equations, respectively.

[0040]

$$R_{pre} = \sum_{k=1}^{K} (E[\hat{P}_k(n-1) \cdot P_k(n)^*])^2$$

Equation (1.1)

[0041]

$$R_{nxt} = \sum_{k=1}^{K} (E[\hat{P}_k(n+1) \cdot P_k(n)^*])^2$$

Equation (2.1)

[0042]

$$R_{pre} = \sum_{k=1}^{K} (E[\hat{Q}_k(n-1) \cdot Q_k(n)^*])^2$$

Equation (3.1)

[0043]

$$R_{nxt} = \sum_{k=1}^{K} (E[\hat{Q}_k(n+1) \cdot Q_k(n)^*])^2$$

Equation (4.1)

[0044]

$$R_{pre} = \sum_{k=1}^{K} \left((E[\hat{D}_{k-1}(n-1) \cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n-1) \cdot D_k(n)^*])^2 \right)$$

[0045] Equation (5.1)

[0046]

$$R_{nxt} = \sum_{k=1}^{K} \left((E[\hat{D}_{k-1}(n+1) \cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n+1) \cdot D_k(n)^*])^2 \right)$$

[0047] Equation (6.1)

[0048] The method and related device disclosed in the embodiments of the present invention for detecting ISI/ICSI in an OFDM system for adjusting a boundary of the OFDM system first computes correlation values to predict the source of the ISI/ICSI and then adjusting the boundary after the source of the ISI/ICSI is determined. Therefore, the performance of tracking the boundary of the OFDM sys-

tem is greatly improved.

[0049] Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.